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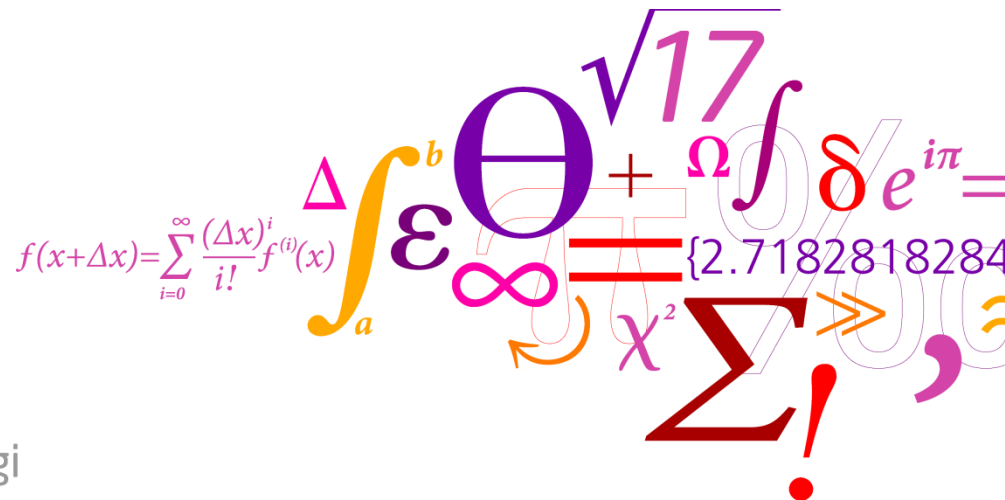
Frequency modeling of wind power fluctuation and the application on power systems

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Wind Division, Risø DTU

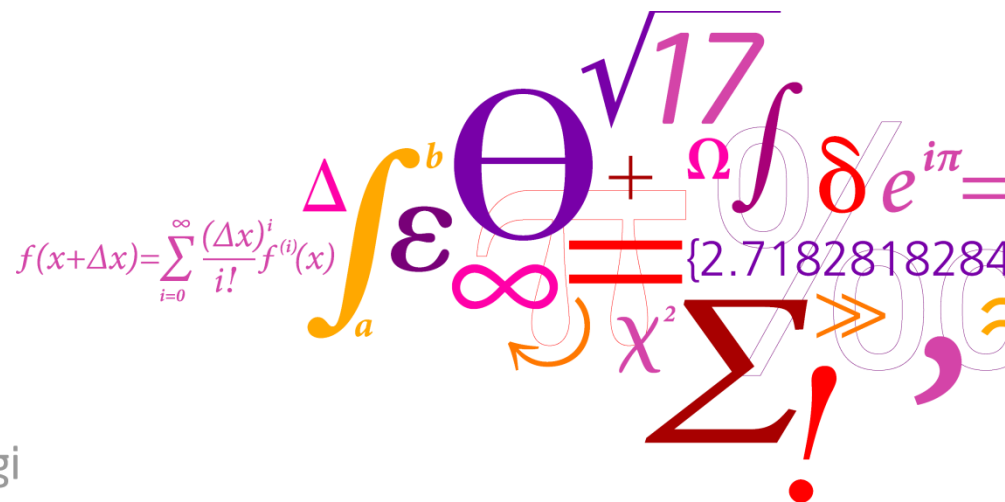
LIN Jin, SUN Yuanzhang, LI Guojie

Tsinghua University



Outline

- Introduction
- Frequency modeling of wind power
- The application in power system
- Conclusion



A collage of mathematical symbols including integrals, summations, and various Greek letters.

$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$
$$\int_a^b \varepsilon \Theta^{\sqrt{17}} + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$
$$\chi^2 \sum !$$

Introduction

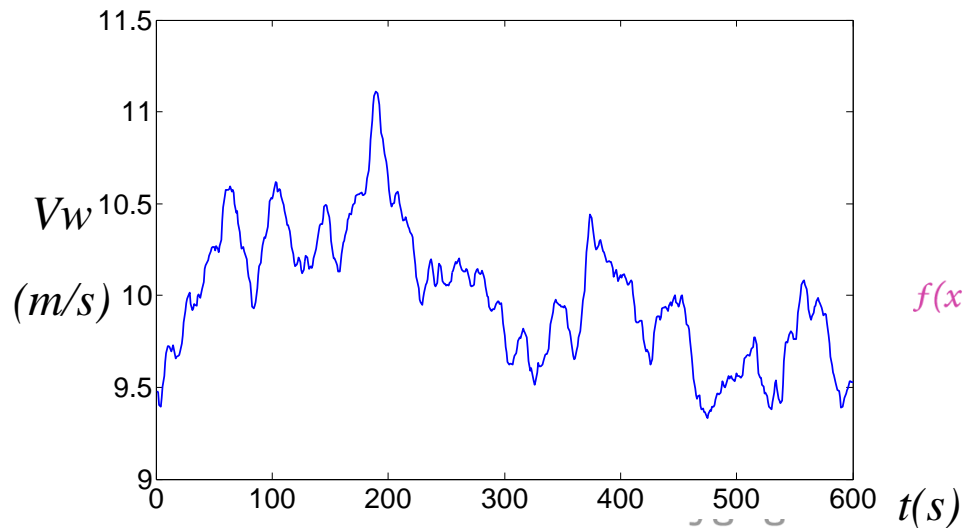
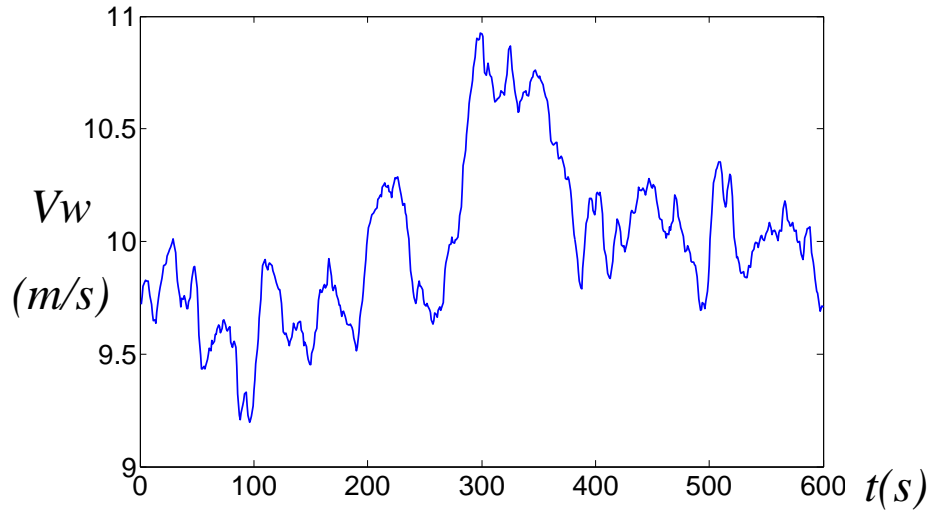
- The penetration of wind power is rapidly growing
- Power fluctuation is a nature characteristic of wind power
- Especially a concentrated wind farm may bring more fluctuation injection
- Balance Grid V.S. Fluctuated Wind

$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

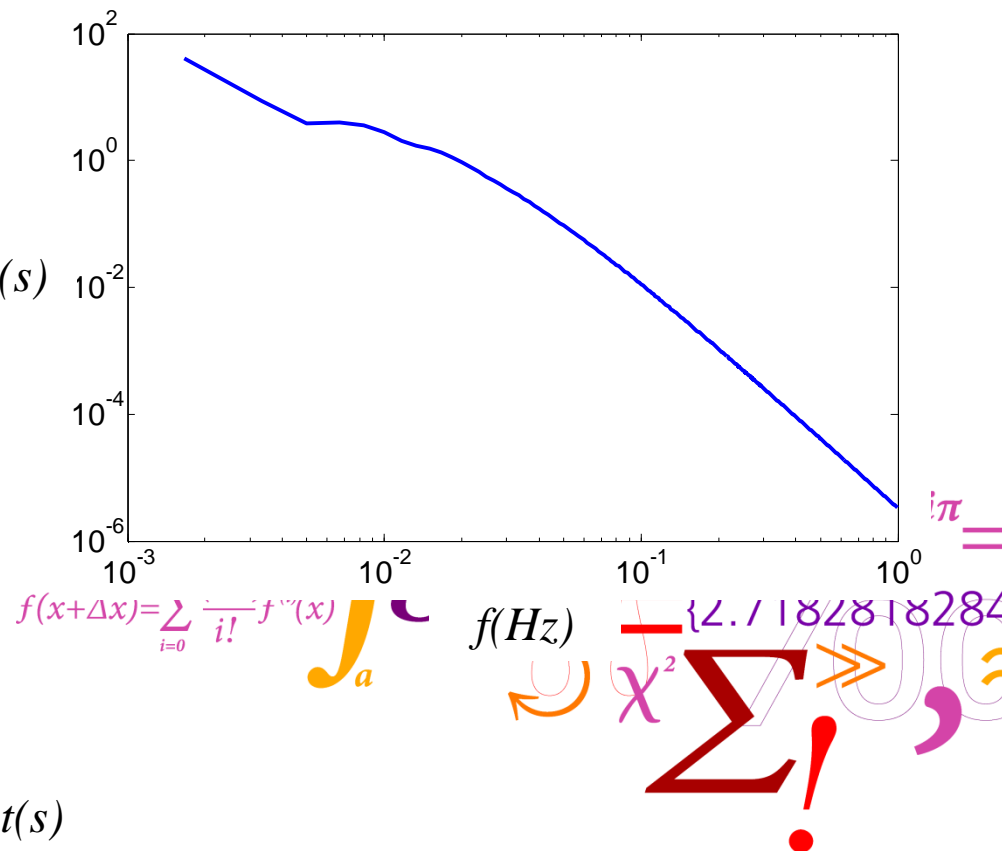
$$\int_a^b \varepsilon \Theta^{\sqrt{17}} + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\chi^2 \sum!$$

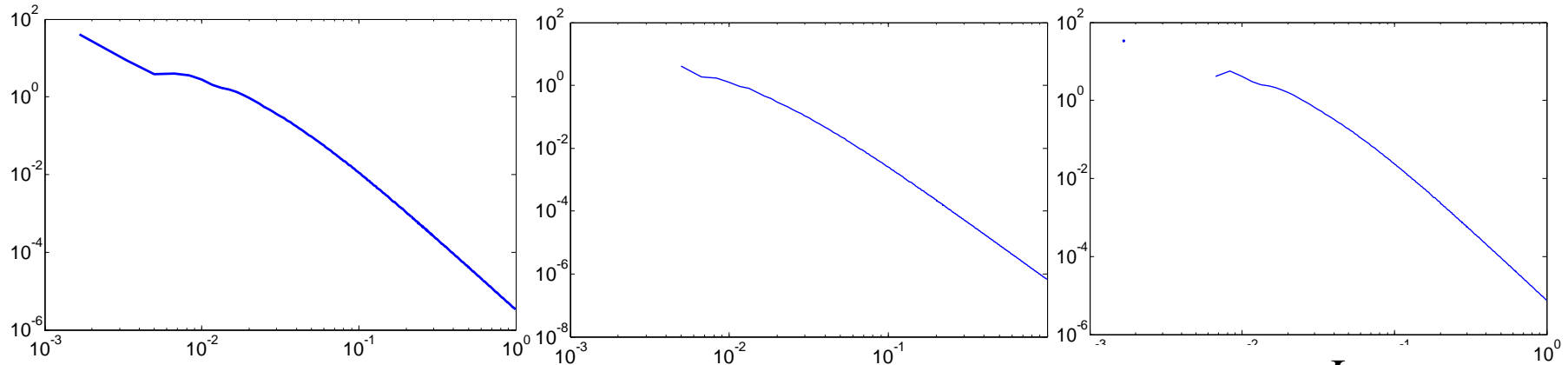
Frequency modeling of wind



PSD



Frequency modeling of wind

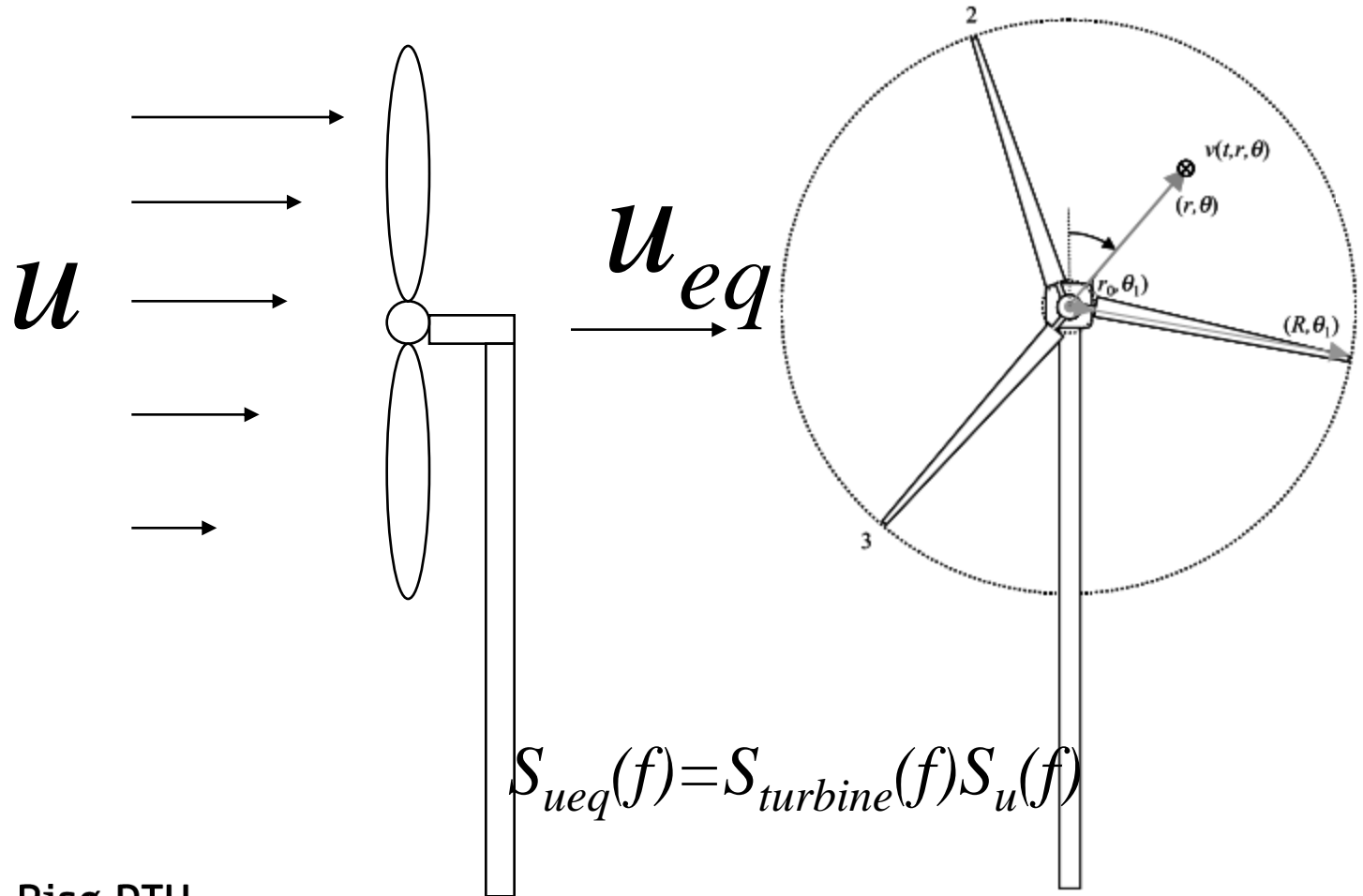


$$S_{LF}(f) = (\alpha_{LF} V_0 + \beta_{LF})^2 \frac{\frac{z}{V_0}}{\left(\frac{zf}{V_0}\right)^{5/3} \left(1 + 100 \frac{zf}{V_0}\right)}$$

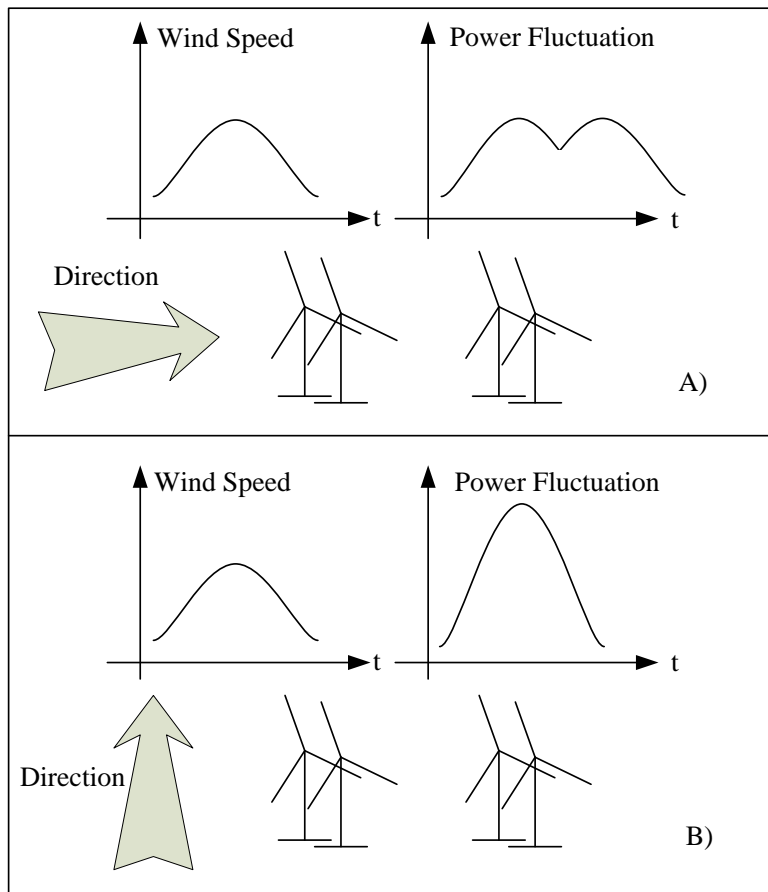
$$S_{IEC}(f) = \sigma^2 \frac{2 \frac{L_1}{V_0}}{\left(1 + 6 \frac{L_1}{V_0} f\right)^{5/3}}$$

$$S_u(f) = S_{IEC}(f) + S_{LF}(f)$$

Equivalent wind passing through wind turbine



Coherence matrix of wind farm



$$\gamma_{[1,1]}(f)$$

$$\begin{pmatrix} \square & \square & \square & \dots & \square \\ \square & \square & \square & \dots & \square \\ \square & \square & \square & \dots & \square \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \square & \square & \square & \dots & \square \end{pmatrix}$$

Wind Speed
Coherence

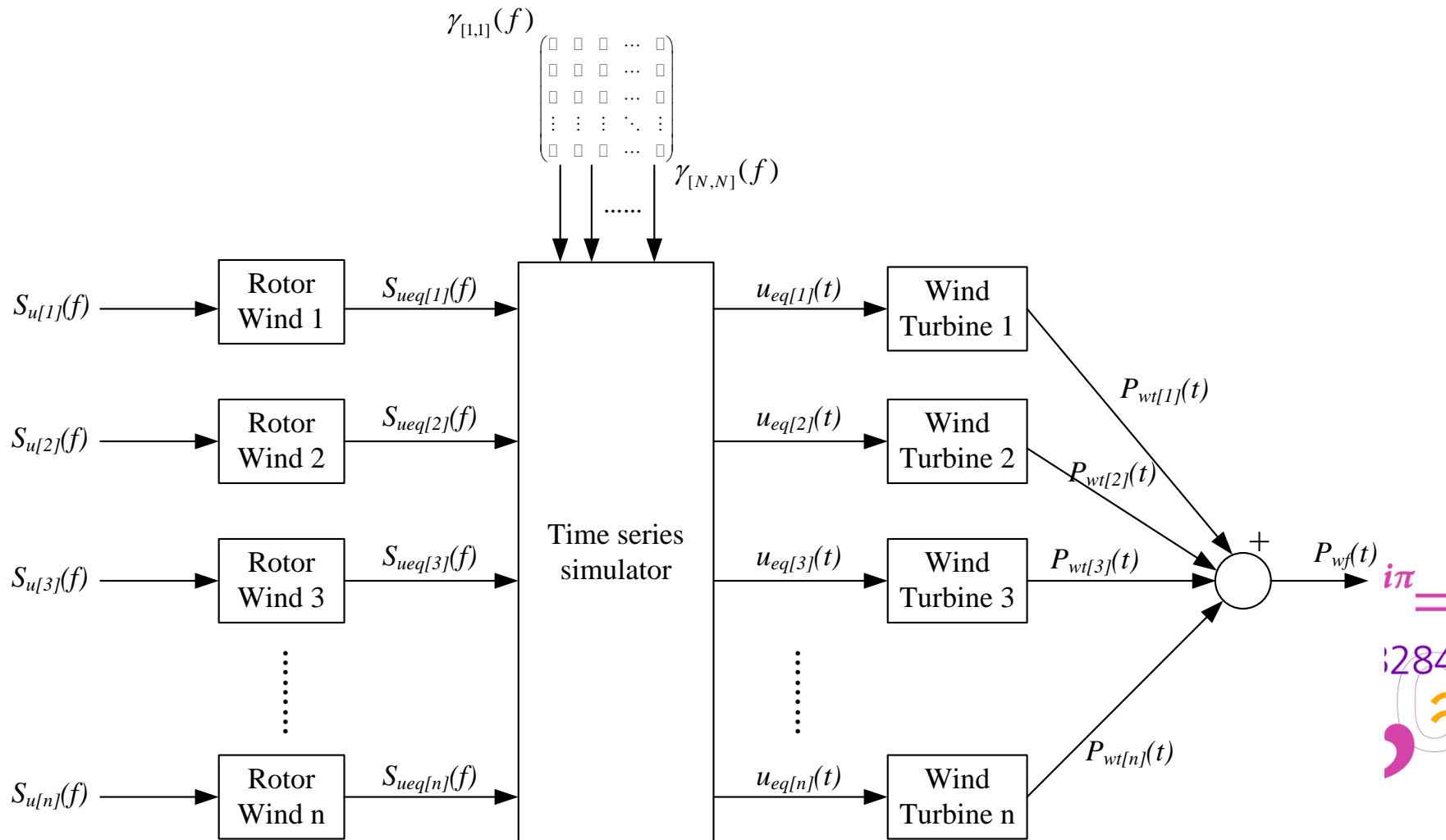
$$\gamma_{[N,N]}(f)$$

$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

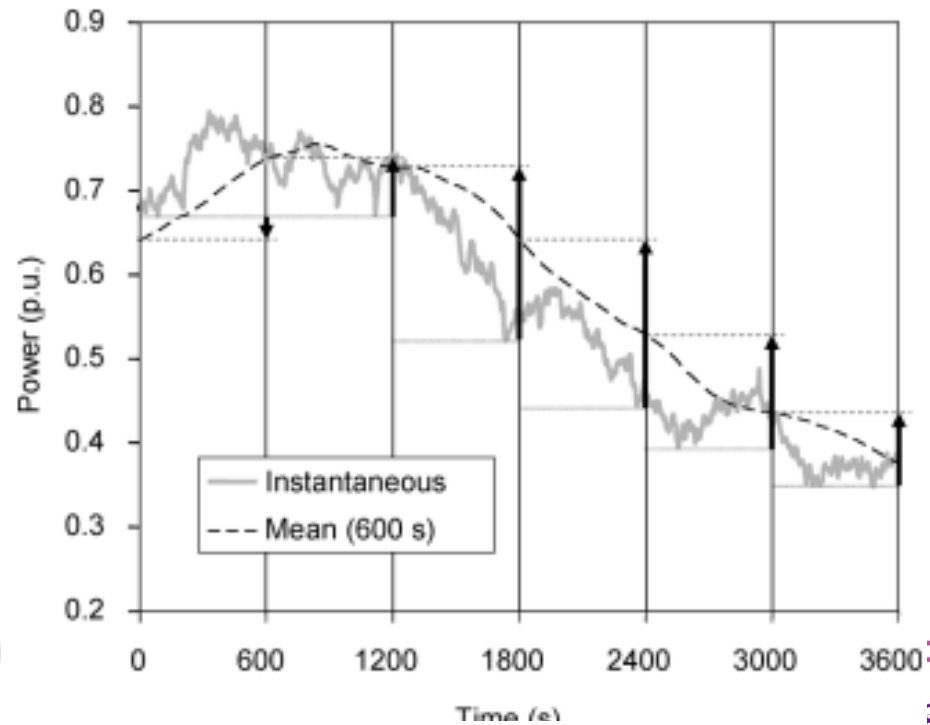
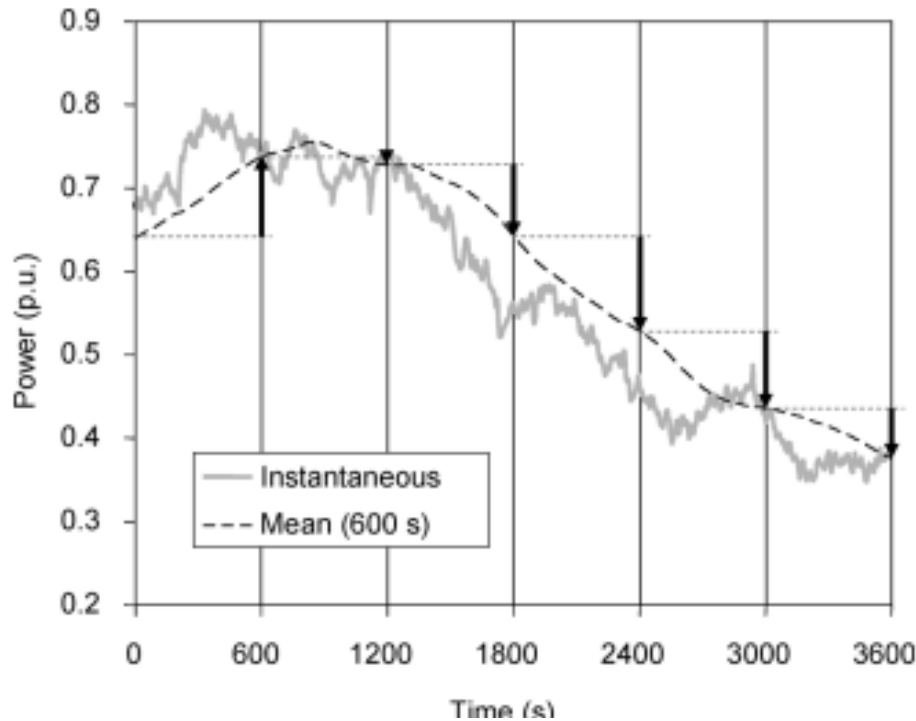
$$\int_a^b \epsilon \Theta + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\chi^2 \sum \gg$$

Frequency modeling of wind power fluctuation



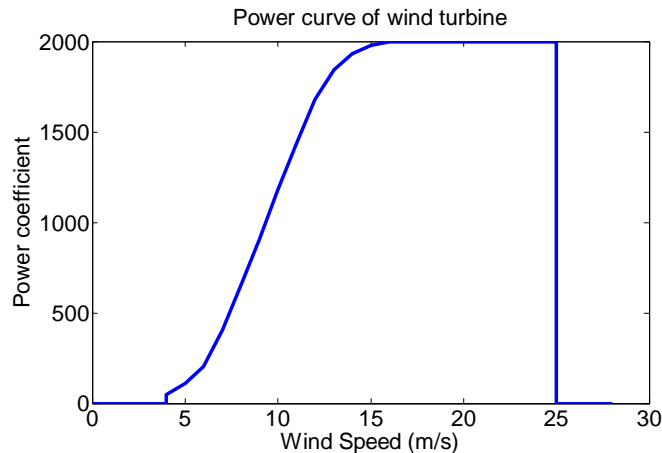
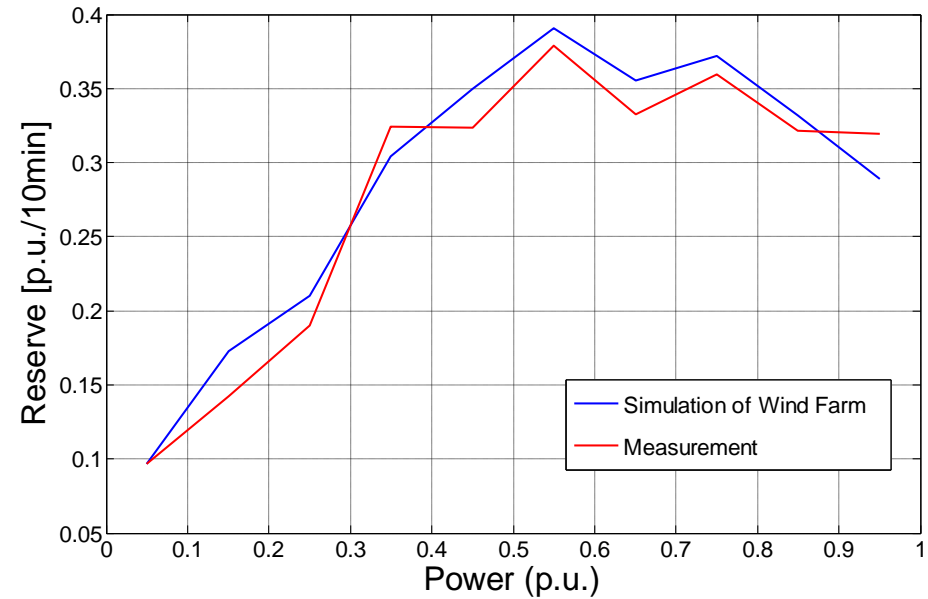
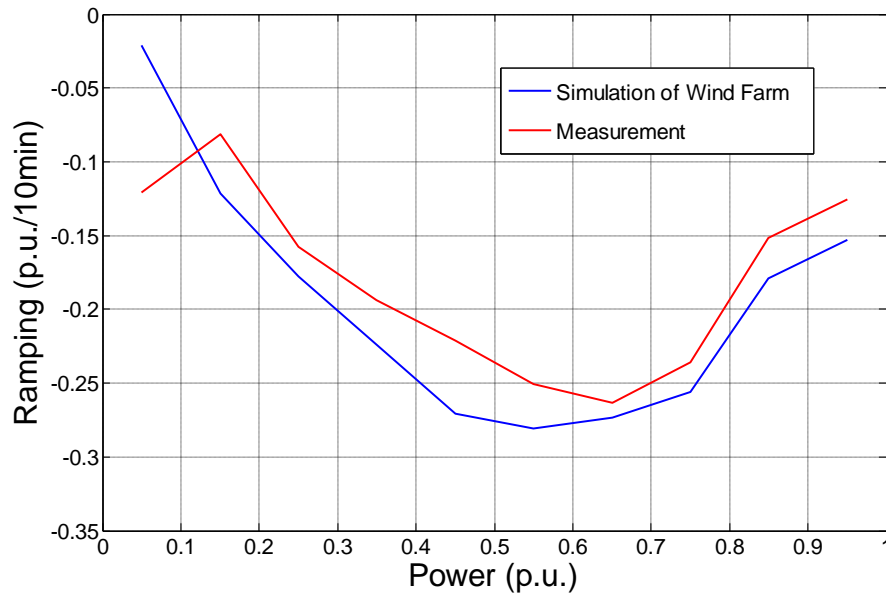
Normal weather condition – ramp and reserve



$$P_{ramp}(n) = P_{mean}(n+1) - P_{mean}(n)$$

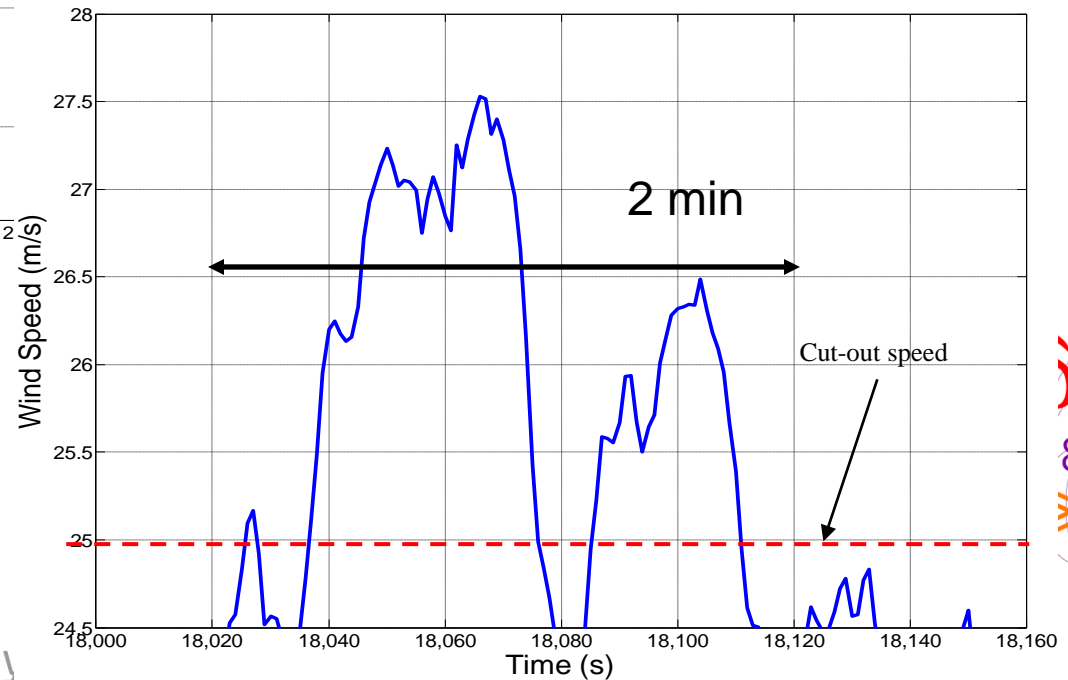
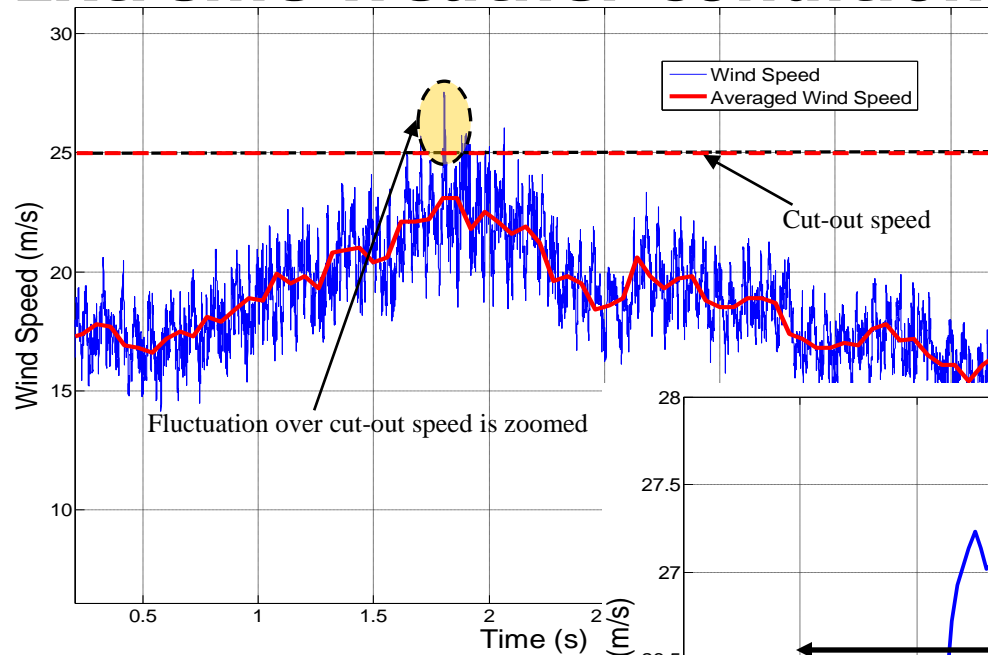
$$P_{res}(n) = P_{mean}(n) - P_{min}(n+1)$$

Normal weather condition — ramp and reserve

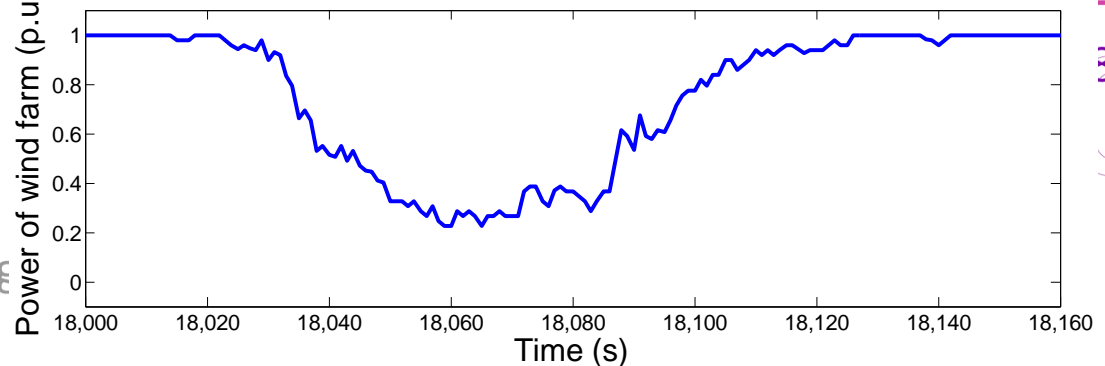
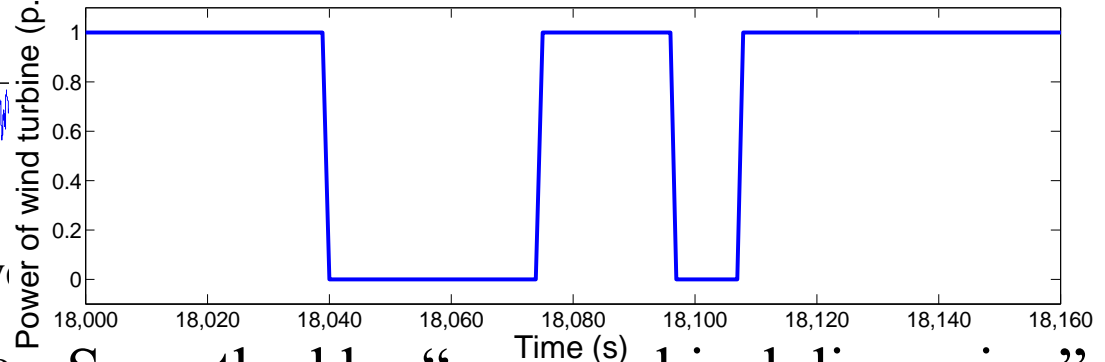
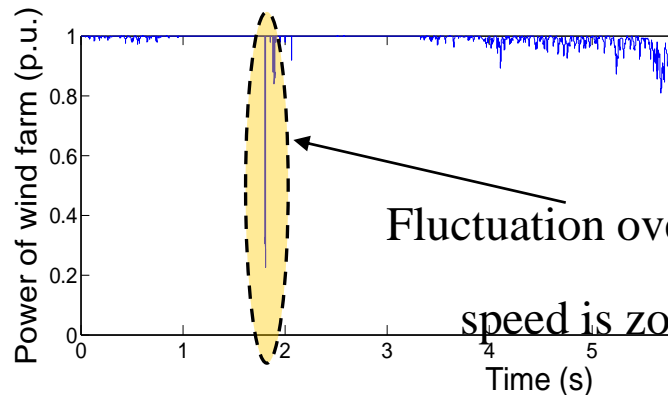
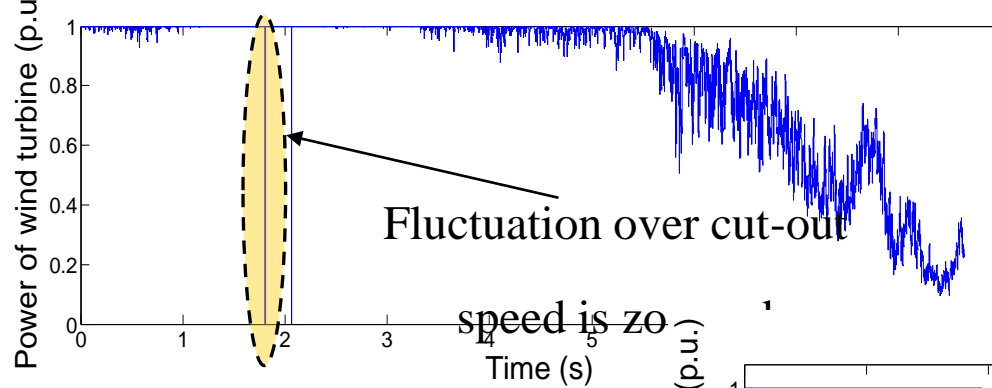


Power fluctuation is sustained near rated power because of the power controller

Extreme weather condition

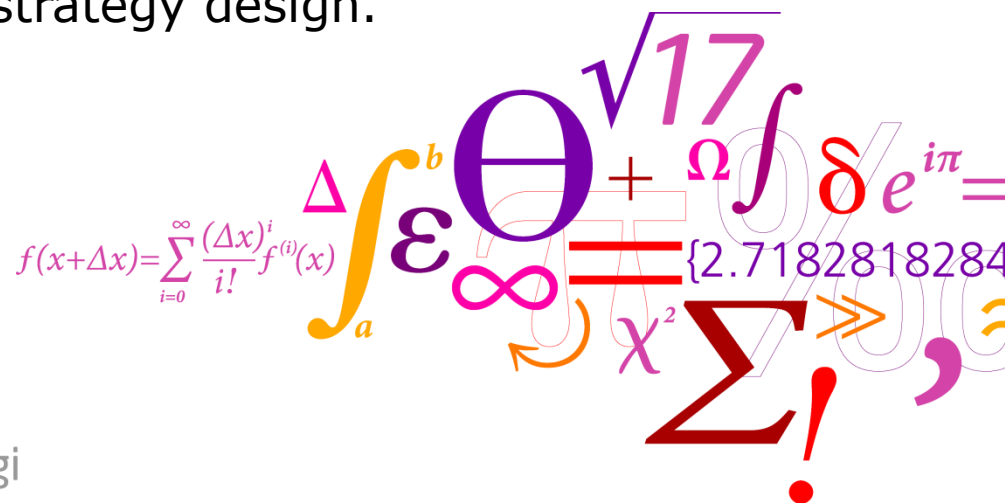


Extreme weather condition



Conclusion

- Frequency model provides an unified way to describe the wind power fluctuation
- Simulation length can be hour to hour and resolution can be second to second
- Under normal condition, highest fluctuation risk happens when the wind farm is producing 0.7-0.9 p. u.
- Under extreme condition, "geographical dispersion" is simulated, which smoothes the power drop when a storm hits.
- In future, this model is extended to assess the frequency deviation risk and the smooth strategy design.



$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

$$\int_a^b \epsilon \Theta^{\sqrt{17}} + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\chi^2 \sum !$$

Thank you!

$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

$$\int_a^b \varepsilon \Theta + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\sqrt{17}$$

$$\infty$$

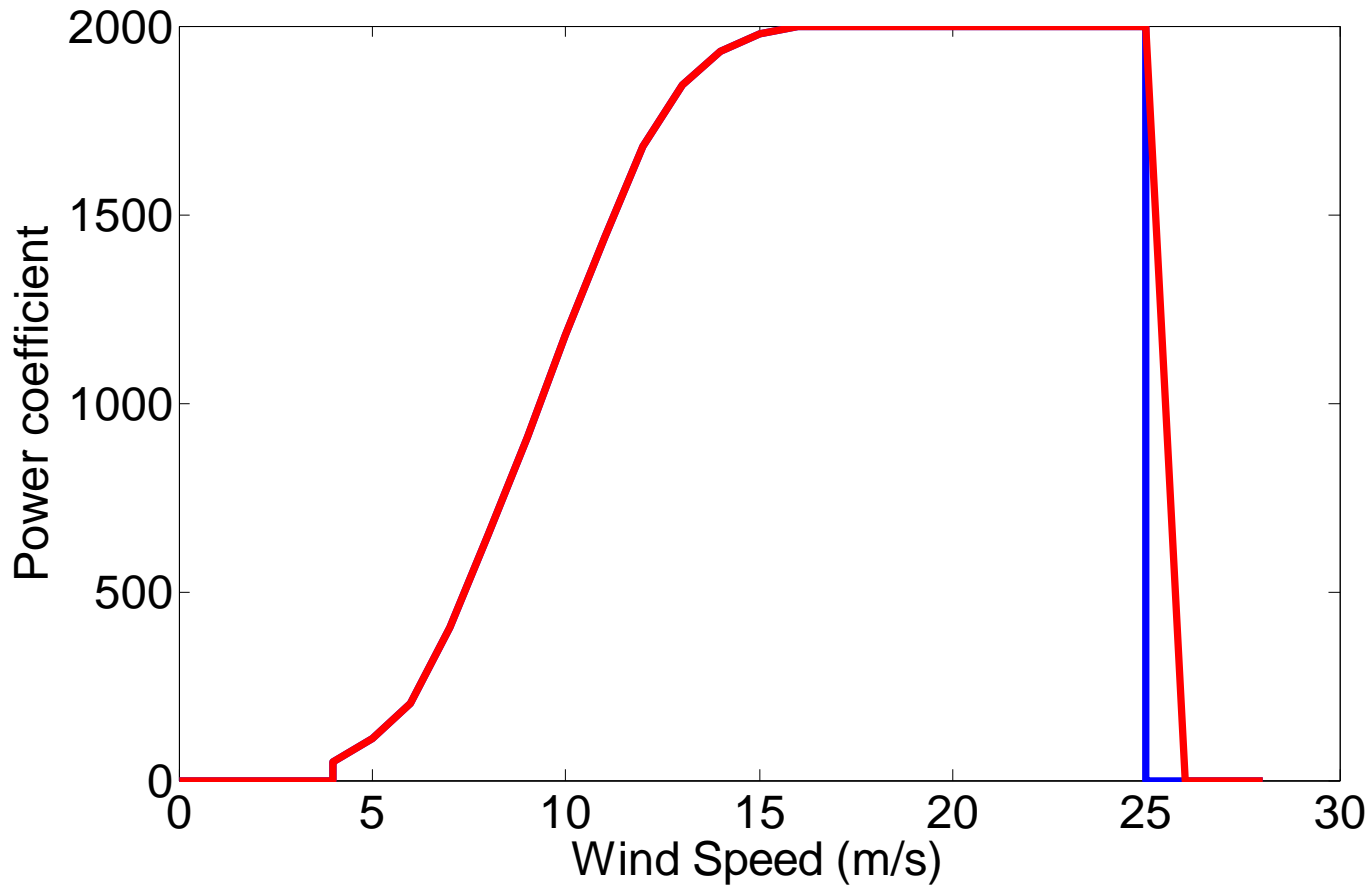
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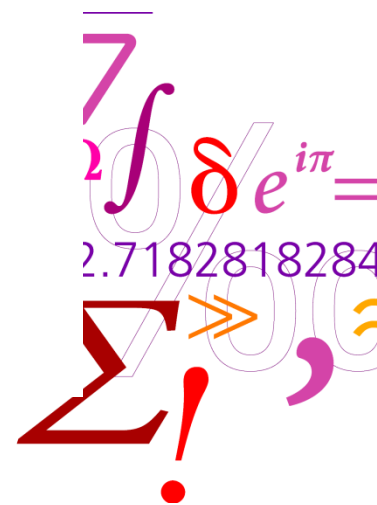
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Extreme weather condition

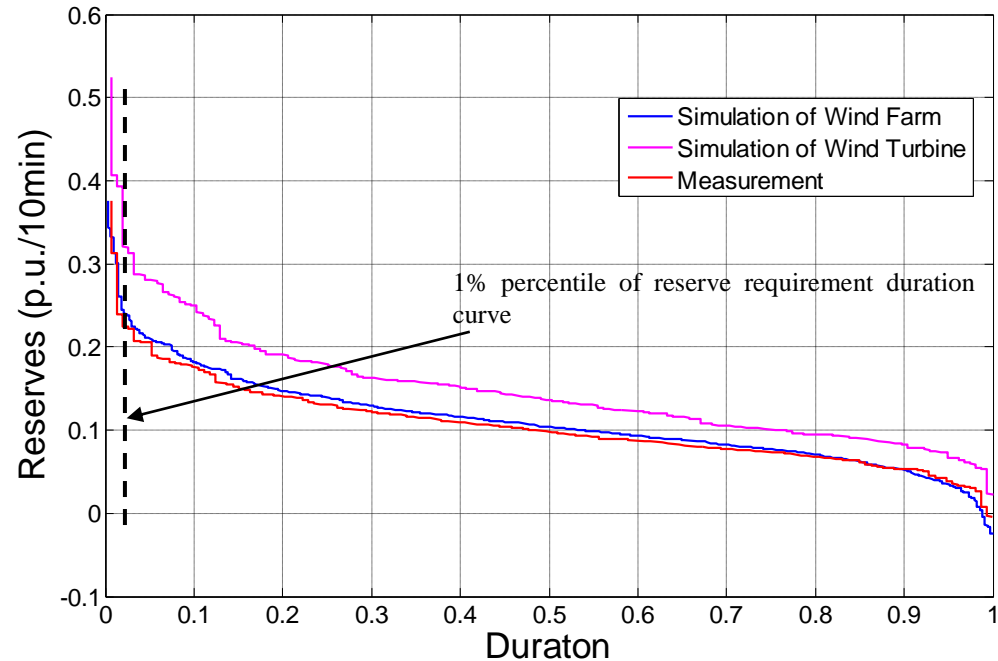
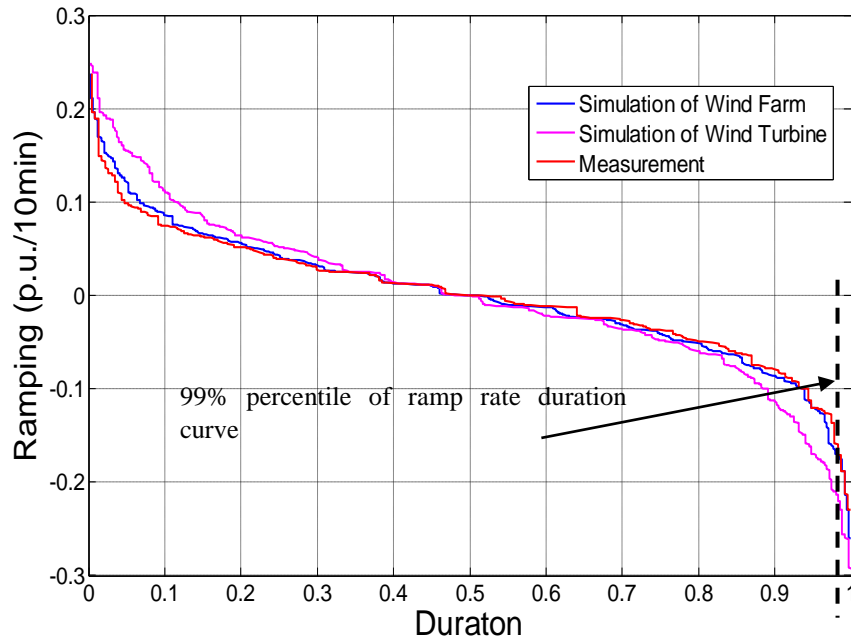


Risø DTU

Nationallaboratoriet for Bæredygtig Energi



Ramp and Reserve



$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

$$\int_a^b \epsilon \, dx = 2.7182818284$$

$$\chi^2$$

$$\sum$$